Partial discharges in power transformers

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Abstract. Tansformers are among the most responsible and expensive elements of the power system, therefore monitoring the technical condition of the transformer is an important and urgent task. One of the signs of aging of insulation in a transformer may be partial discharges (PD), leading to its further failure. The use of monitoring systems based on PD analysis makes it possible to prevent the severe consequences of short circuits in transformers and, as a result, achieve significant economic effects during the operation of controlled high-voltage equipment. The transformer monitoring system based on the partial discharge method is complex and not always effective, because fixed discharges in transformer insulation can be observed for years and do not lead to breakdown, and among the PD it is not always possible to identify the leader's transition to the through phase in time, which creates sufficient conditions for breakdown. In practice, the discharge test is performed using chromatographic analysis of dissolved gases in oil (CADG) or by measuring discharge activity. The article analyzes the effectiveness of PD control methods and the need to develop mathematical models of partial discharges that allow studying the dynamics of the streamer-leader transition in controlled isolation.

1 Introduction

Transformers are one of the most expensive components of the electric power infrastructure. Although they are reliable, the failure of one of them leads to serious consequences, interruptions in power supply and under-supply of electricity costs billions of dollars [1-11]. High-voltage equipment occupies an important place in the development of the Russian electric power industry of the 21st century, when considering the issues of stable operation of electric power systems [2]. The leading function of high voltage in power transmission lies in the transmitted power, which increases in proportion to the square of the rated voltage. In this regard, there is a need to improve the current complex of high-voltage equipment for generating, transmitting and distributing electric energy: generators, transformers, power transmission lines, etc.

During the monitoring of high-voltage equipment, special attention is paid to the issue of the operation of control systems based on the analysis of partial discharges. In particular, such systems are used in high-voltage transformers [12-15]. The construction of mathematical models of the PD allowing to study amplitude-phase, amplitude-frequency and frequency-time oscillograms of discharges with the determination of the probable type

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of defect and prediction of its development will increase the effectiveness of the method, reduce the error of the calculation results of the residual resource. Despite long-term studies of this topic since the 60s, to date, there are no perfect diagnostic methods and universal mathematical models that can accurately answer the question of the residual insulation life of a transformer by the PD method in online mode.

Based on the above, the task is very difficult, requiring knowledge from the researcher in the field of materials science, chemistry, physics, electrical engineering, but most likely also programming languages and work with artificial intelligence to process a large stream of discharge data and identify diagnostic signs of the PD [13-20].

2 Materials and methods

It is proposed to use the method of registration of partial discharges based on mathematical models of the PD to ensure the necessary online/offline control. It should be noted that today there is no shortage of technical solutions for hardware from world manufacturers that allow solving the problem of predictive analysis of controlled equipment using a single intelligent electronic device.

Insulation damage is one of the most common causes of accidents and loss of electricity by consumers, which is unprofitable (from an economic point of view) for all participants in the electricity market. The power transformer is one of the most emergency elements in the power system and requires additional monitoring and analysis by modern methods [1].

Internal damage in the form of partial discharges occurs due to changes in the normal characteristics of the transformer oil. The properties of the oil can be affected by the aging of the insulation itself, as well as signs such as: humidification, pollution, ingress of gases. The condition of the oil is assessed based on the results of tests, which, depending on the volume, are divided into three types (electrical strength tests, abbreviated oil analysis, full oil analysis) [4]. However, the confidence level of chromatography leaves much to be desired, it is 70-80 % [1, 14]. This was determined 20 years ago by the "CIGRE" 15.01 working group. Therefore, along with the CADG, it is necessary to control partial discharges. In this case, the reliability increases to 100% [14].

The study of the PD has not progressed far today, compared with the 60-70 years, some still do not believe in their existence. Based on the literature, discharges have great consequences (Fig. 1) [5].

Fig. 1. Destruction of the tank at the 330 kV substation and damage to the input (source: Investigation of the causes of CR in power oil-filled transformers, N. V. Gruntovich, E. A. Zhuk, Scientific electronic library "CyberLeninka", 2019, p. 60).

Such defects in insulation can be sources of discharge activity, occur in a variety of transformer elements: failures in the windings of power transformers are the cause of 35% of transformer failures [10], these flexible transformer elements are in the tank in an insulating oil environment, high-voltage inputs, "RPN", transformer core. It is also necessary to take into account the peculiarities of the polarity of the discharge, which is always opposite to the external field.

Acoustic recording is the simplest method of recording partial discharges, based on the measurement of ultrasonic vibrations. Taking into account the partial discharge analysis device and the location of defect zones in the insulation of AR-700 high-voltage equipment (Fig. 2), an experiment was conducted to measure discharge activity [6]. Observing the waveforms of acoustic signals, it can be concluded that, despite their cheapness and ease of operation, the sensors have low filtering of external interference. When measuring PD, obstacles in the network can arise due to various reasons: sources of high-frequency voltages and sudden changes in current, vibration of equipment. Additional interference can be caused by radio transmitters, PD in neighboring equipment, discharges between tires, discharges between elements of current pipelines, discharges on the pointed edges of fittings or at the ends of knives of disconnected disconnectors, etc. [7]. To maintain reliability, the registration equipment must automatically determine the type of defect and analyze the rate of its development. If we proceed from the very need of measuring equipment, then its function should ensure maximum noise immunity and sensitivity in the event of pulse signals of partial discharges. These monitoring elements are electronic sensors: intelligent partial discharge sensors, as well as the use of high-voltage inputs as measuring capacitors. Such equipment has a sufficiently high frequency range, which solves one of the problems of distrust of diagnostic measurement.

Fig. 2. Installation of acoustic sensors (source: Production of electronic components: website: non-commercial. the online version. http://www.nicostrans.ru (accessed 11.04.2024)).

Such a technology for monitoring power equipment has existed relatively recently, the modern direction of development of the power system assumes a high share of responsibility that must be assigned to digital decision-making and system monitoring systems. An example is the Smart-PD/2 brand intelligent partial discharge sensor operating in the UHF range [8]. To detach from high-frequency interference, two antennas are used in the sensor, located on the outer and inner sides of the tank, thus technically separating defects in insulation, and the presence of an expert system increases staff awareness due to greater informativeness. The number of installed sensors is recommended in the region of 10 pieces [9].

The reliability of power transmission in a large case also depends on the high-voltage inputs of power transformers. Due to its external and internal insulation, as well as design features, such "amazing" equipment is the best place to register partial discharges. Measuring communication capacitors are the only equipment that is connected to high–voltage inputs. The series-connected coupling capacitors themselves, as such, are not meters, rather they divide the voltage than measure it. However, when an active or inductive resistance divider is connected to the lower plate, the output voltage will begin to change with increasing current pulses [8, 21-23].

3 Results and discussion

Power transformers are static devices that transfer electrical energy from one circuit to another without changing the frequency. They have different types, characteristics and applications depending on their design, functions and purpose [13]. The selection of various sensors is carried out depending on different subsystems of the equipment, taking into account the operation of the controlled transformer, its load, transients, power characteristics, and general technical condition.

The requirements for monitoring the insulation discharges of power transformer equipment are described in the regulatory and technical documentation. The main requirements for checking these devices include [3]:

− continuous measurement, registration and display of the main parameters of transformers of voltage classes 220-750 kV in normal, pre-emergency and emergency modes;

− the monitoring system should be based on a three-level system. According to this requirement, level 1 includes primary sensors, level 2 is a monitoring unit, level 3 is designed for: mathematical processing, computational and analytical tasks, remote configuration;

− assessment and forecasting of the technical condition of transformers.

When monitoring in electrical installations, according to the above requirements, problems arise related to technical difficulties associated with the use of measuring equipment, since the higher the frequency of the recorded pulses, the more expensive and more complex the equipment.

Careful selection of recorders (sensors), and methods of measurement and mathematical modeling of discharges will improve the prediction of changes in the technical condition of insulation at future stages of transformer operation, optimal timing and volumes of necessary repair and service actions. It will simplify the configuration of power transformers, reduce the likelihood of personnel errors and increase the reliability of the substation circuit and equipment, reduce the number of emergency shutdowns and wear of the main switching equipment, which will certainly affect energy efficiency and energy saving.

It is worth noting that the proposed monitoring of partial discharges is currently used to evaluate cables and transformers, due to distrust and difficulty in operation, this technology is very rarely used. In this case, it is proposed to increase the coverage of the location of registration of equipment to clarify the information content of protective switching devices, as well as to identify diagnostic signs of discharge due to additional study by the PD modeling method.

Modeling allows you to analyze and study the discharge at a more accurate level. However, it is difficult to simulate and design the physical phenomenon of the PD due to the differences between modeling and the real requirements of observability and realism [16, 18]. The most frequent and simplest and most frequent method is the ratio of the amplitude of the pulse and the phase of the applied alternating voltage. The color, or tone, shows the number of pulses, the frequency of their repetition, having the same parameters [17, 24] (Fig. 3).
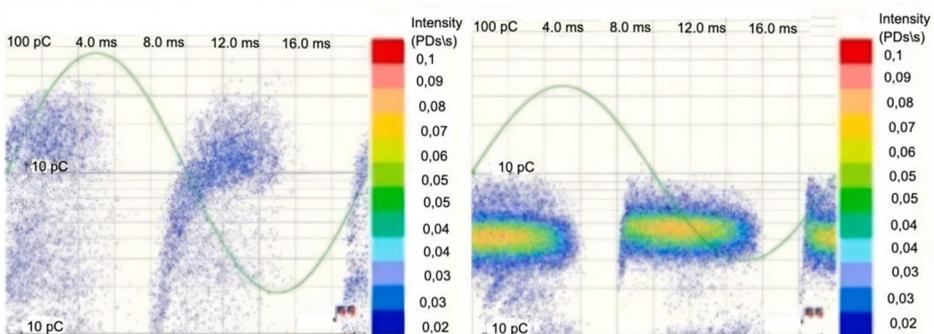

Fig. 3. 2D partial discharge model.

The 2D model is the most convenient image of the insulation defect. It is planned to use COMSOL Multiphysics for full visualization in the 3D model. Conducting discharge physics simulation implies a high level of competence and a huge amount of information. There are great difficulties in finding data on the properties of the system and the

parameters of the constituent chemical reactions in it. The study of the influence of the main parameters on the activity of partial discharges is crucial to improve the accuracy and reliability of diagnostics.

The results of the PD simulation will make it possible to create a library of defect data in isolation for use in microprocessor monitoring devices [22], namely in intelligent electronic devices (IEDs) for the purpose of defect recognition. The use of IED in on-line mode with filtering of the dynamics of critical PD will increase the efficiency of the method, reduce the error of the calculation results of the residual resource of the controlled object and carry out repairs of equipment according to condition.

4 Conclusion

With the development of digital technologies in the electric power industry, the use of intelligent electronic devices (IED) and remote methods of recording, transmitting and controlling information, the observability (control) of power equipment, its automation and the ability to adapt to operating conditions are increasing, which, in turn, increases the reliability of power supply to consumers of electric energy. Minimization of human resources in assessing the residual resource of monitoring equipment, reduces the labor costs of teams of electrical laboratories, eliminates the human factor of erroneous conclusion about the state of the network, additionally allows you to adjust the schedule for the withdrawal of electrical equipment for repair.

From the information collected, conclusions can be drawn:

− thanks to the advanced functionality, the use of the diagnosed equipment allows you to increase the reliability of the technical condition of insulation in the transformer at different frequency levels;

− the proposed method provides high-voltage equipment with constant monitoring and attention, which significantly increases the reliability of the equipment, thereby solving the main problem of the transformer;

− to achieve the maximum effect of the proposed measuring instruments, it is necessary to classify the equipment according to the main parameters;

− the issue of organizing the registration of partial discharges in a transformer with an increase in voltage is one of the necessary tasks carried out to identify defects in insulation.

− the development of mathematical models that allow studying the CR takes another step towards reducing the error in calculating predictive isolation analysis.

Thus, monitoring transformers based on partial discharge is an important element in the power system, which is still worth considering.

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